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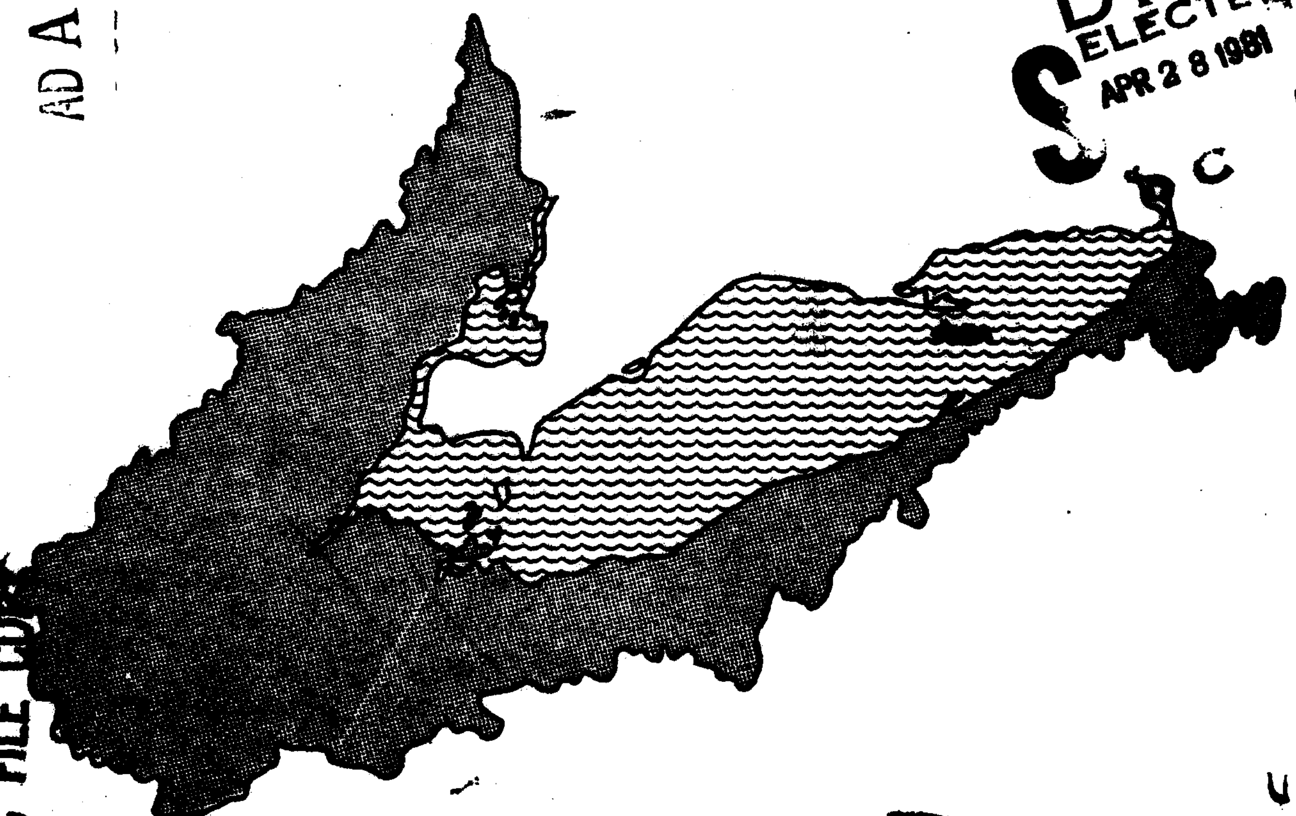

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A major shift from conventional tillage to conservation tillage will be required to reduce soil loss and diffuse sources of phosphorus in the Lake Erie drainage basin. This shift will require some changes in the kinds and amounts of pesticides used and may change the losses of these compounds in runoff. Alachlor, atrazine and butylate account for about 77% of the herbicide used in Indiana, Michigan and Ohio, and carbofuran, fonofos and terbufos represent about 86% of the insecticide use. Most of the pesticides in use in the basin today are relatively nonpersistent and have low mammalian and fish toxicities. A major shift to conservation tillage will increase use of paraquat and

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) glyphosate herbicides and reduce the use of soil-incorporated materials such as butylate and trifluralin. About 1% of applied pesticide is lost in runoff, much of it in the first event after the compound is applied. Pesticide losses are reduced with increased surface cover, but this effect decreases with pesticides that are watersoluble and have only moderate to low affinity for soil particles. Losses of pesticides from agricultural land in the Lake Erie basin are not expected to measurably change with a shift to conservation tillage.

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PESTICIDE USE IN THE LAKE ERIE BASIN AND THE IMPACT OF ACCELERATED CONSERVATION TILLAGE ON PESTICIDE USE AND RUNOFF LOSSES

by

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January, 1981

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ABSTRACT

A major shift from conventional tillage to conservation tillage will be required to reduce soil loss and diffuse sources of phosphorus in the Lake Erie drainage basin. This shift will require some changes in the kinds and amounts of pesticides used and may change the losses of these compounds in runoff. Alachlor, atrazine and butylate account for about 77% of the herbicide used in Indiana, Michigan and Ohio, and carbofuran, fonofos and terbufos represent about 86% of the insecticide use. Most of the pesticides in use in the basin today are relatively nonpersistent and have low mammalian and fish toxicities. A major shift to conservation tillage will increase use of paraquat and glyphosate herbicides and reduce the use of soil-incorporated materials such as butylate and trifluralin. About 1% of applied pesticide is lost in runoff, much of it in the first event after the compound is applied. Pesticide losses are reduced with increased surface cover, but this effect decreases with pesticides that are water-soluble and have only moderate to low affinity for soil particles. Losses of pesticides from agricultural land in the Lake Erie basin are not expected to measurably change with a shift to conservation tillage.

INTRODUCTION

The Lake Erie Wastewater Management Study (LEWMS) has determined that conservation tillage practices can significantly reduce gross erosion from cropland in the Lake Erie basin (Corps of Engineers, 1979) and that this reduction can provide a large part of the reduction in the non-point source phosphorus load required to improve water quality in the lake. There is an opportunity for farmers in the basin to shift a significant proportion of the cropland acreage from conventional tillage to minimum tillage and no tillage with no economic loss (Forster, 1978).

While the effectiveness of conservation tillage in reducing erosion and phosphorus loss is well documented (Logan and Adams, 1981), there is some concern about the increased use of pesticides (especially herbicides) with tillage reduction and the subsequent fate of these compounds in the environment. More herbicide is requried in no till to take the place of tillage and more insecticides may also be required in some instances.

Since the prohibition in the 1970's of persistent chlorinated hydrocarbons such as DDT, aldrin, dieldrin, heptachlor and others, the concern over the widespread use of pesticides has abated somewhat. Presently the greatest concern is for compounds such as toxaphene which are not extensively used in the northern grain belt, of which the western Lake Erie basin is a part. Most compounds in use today are more degradable, less toxic and less biomagnified than some used previously. Nevertheless, there is sufficient caution concerning the use of pesticides that an increase in their use with conservation tillage warrants some analysis of the situation. If we restrict the discussion to those crops with the largest pesticide-treated acreage in the basin , we are primarily concerned with corn and soybeans. In Ohio in 1978, corn and soybeans together accounted for 98% of the acreage treated with herbicides and corn alone accounted for 87% of the acreage treated with insecticides (Carter et al, 1980). In addition, these are the crops that will see most of the shift from conventional tillage to no till.

Another important component of the pesticide perspective is the relative usage of herbicides and insecticides. Of the total herbicide and insecticide usage on corn and soybeans in Ohio, 86% of that used on corn in 1978 was herbicide and 99.7% of that on soybeans was herbicide (Carter et al, 1980). The relative hazard to man and the environment is generally lower for herbicides than for insecticides.

A shift from conventional tillage to conservation tillage and especially no till will have some predictable effects on pesticide use. First, preplant herbicides which require immediate soil incorporation will no longer be used. These include butylate (Sutan) and EPTC (Eptam, Eradicane) which are two of the ten compounds most used in Ohio (Table 7). The insecticide chlordane is also primarily incorporated. Secondly there will be an increase in the use of non-selective herbicides for weed and mulch cover control. Paraquat and glyphosate (Roundup) are the two most commonly used compounds in this category and their use would increase greatly from the present. In 1978 , paraquat was only 0.19% of all herbicides used in Ohio and glyphosate use was 0.14% of the total.

Other questions for which answers are less immediately apparent are the extent to which total pesticide use will increase with conservation tillage and the extent to which pesticide losses in runoff from conservation tillage will differ from those with conventional tillage.

The objectives of this report are to identify the major pesticide compounds used in the Lake Erie basin, analyze the available data on pesticide runoff, examine recommendations for pesticide use in no till corn and soybeans and to assess the major potential environmental effects from pesticide use on expanded conservation tillage acreages.

PESTICIDE USE IN THE GRAIN-PRODUCING STATES OF THE LAKE ERIE BASIN - INDIANA, MICHIGAN AND OHIO

Indiana

Table 1 gives the top ten herbicides and insecticides used in Indiana in 1978, while Table 2 gives the percent of planted acreage treated with pesticide and the acres treated for Indiana's major crops. Table 2 also gives similar data for the northeastern region which includes most of the area in the Lake Erie drainage basin. Corn was the most heavily treated crop with almost 100% of the planted area receiving herbicides and about 50% treated with insecticides. Almost all of the soybean acreage received herbicides, but very little insecticide. Other crops received little or no treatment for weeds or insects except alfalfa where about 10-20% of the acreage received insecticide. Table 3 shows that alachlor is a major herbicide for both corn and soybeans and atrazine is the most used herbicide on corn. Together with butylate which is used exclusively on corn, these three compounds account for 78% of the herbicide used in Indiana. Almost all insecticide is used on corn with carbofuran, fonofos and terbufos accounting for 84% of the insecticide used in the state.

Table 1. Common and trade names of the top ten herbicides and insecticides in Indiana ranked according to annual usage (Liska *et al*, 1980).

	Common Name	Trade Name	Mode of Usage†
Herbicides			
1	Alachlor	Lasso	PRE, PRP-INC
2	Atrazine	Atrazine, Aatrex	POE, PRE, PRP-INC
3	Butylate	Sutan	PRP-INC
4	Trifluralin	Treflan	PRP-INC
5	Metribuzin	Lexone, Sencor	PRE, POE, PRP-INC
6	Metolachlor	Dual	PRE, PRP-INC
7	Linuron	Lorox	PRE, POE
8	Cyanazine	Bladex	PRE, PRP-INC
9	EPTC	Eptam, Eradicane	PRP-INC
10	Naptalam and Dinoseb	Dynanap, Ancrack	PRE, POE
Insecticides			
1	Carbofuran	Furadan	
2	Fonofos	Dyfonate	
3	Terbufos	Counter	
4	Carbaryl	Sevin	
5	Chlorpyrifos	Lorsban	
6	Ethoprop	----	
7	Phorate	Thimet	
8	Chlordane	Chlordane	
9	M+M*	M+M	
10	Methidathion	----	

* Malathion and methoxychlor

† PRE = Preemerge; POE = Postemerge; PRP-INC = Preplant and incorporate

Table 2. Acreage of major crops treated with herbicides and insecticides in Indiana in 1978 (Liksa et al, 1980).

	Percent of Planted Acreage Treated With:		Planted Acreage (1000 ac) Treated With:	
	Herbicides	Insecticides	Herbicides	Insecticides
Corn	97.8 (96.0)*	47.1 (51.1)	5,966 (577)	2,875 (296)
Soybeans	95.6 (94.2)	2.7 (0.3)	3,966 (478)	110 (1.4)
Wheat	6.3 (10.1)	0.4 (0.0)	56 (13.5)	3 (0.0)
Other small grains	9.4 (15.6)	3.3 (0.9)	25 (11.9)	9 (0.7)
Alfalfa	3.9 (1.1)	19.8 (9.5)	16 (0.8)	83 (7.2)

* Data for the northeast region which includes most of the Lake Erie basin counties.

Table 3. Herbicides and insecticides used in Indiana in 1978 by major crop (Liska et al, 1980).

	Quantities of material (1000 lb) used on:					
	Corn	Soybeans	Wheat	Other Small Grains	Alfalfa	Total
Herbicides						
Alachlor	5524	3635	--	--	--	9159.0
Atrazine	7853	60	--	3.2	--	7916.2
Butylate	3326	--	--	1.7	--	3327.7
Trifluralin	24	1527	--	--	1.7	1552.7
Metribuzin	13	962	--	--	--	975.0
Metolachlor	694	82	--	--	--	776.0
Linuron	53	617	--	--	--	670.0
Cyanazine	631	4	--	--	--	635.0
EPTC	607	6	--	--	10.2	623.2
Naptalam and Dinoseb	--	433	--	--	--	433.0
	Total					26,067.8
Insecticides						
Carbofuran	1596.5	4.4	--	--	--	1600.9
Fonofos	628.6	--	--	--	--	682.6
Terbufos	433.0	--	--	--	--	433.0
Carbaryl	53.7	79.9	--	--	38.2	171.8
Chlorpyrifos	100.7	--	--	--	--	100.7
Ethoprop	91.4	--	--	--	--	91.4
Phorate	75.9	--	--	--	--	75.9
Chlordane	35.1	--	--	--	--	35.1
M+M*	--	--	--	--	18.5	18.5
Methidathion	--	--	--	--	12.4	12.4
	Total					3222.3

* Malathion and methoxychlor

Michigan

Table 4 lists the major herbicides and insecticides used in Michigan. The only difference between the herbicides used in Michigan and those in Indiana is pyrazon, a sugarbeet herbicide. Also small amounts of the insecticide azinphosmethyl are used on alfalfa in Michigan but not in Indiana. Table 5 shows that the same percentage of corn and soybean acreage is treated with herbicides and insecticides as in Indiana, but a much higher percentage (50 vs 10) of the small grain acreage received herbicide in Michigan. Dry beans and sugarbeets, only reported in Michigan, are also 100% treated with herbicides. Table 6 shows the quantity of each compound by crop. As in Indiana, corn received most of the herbicide and insecticide used in Michigan, but dry beans accounted for more herbicide than did soybeans. Atrazine, alachlor and butylate represented 73% of the herbicide used in Michigan and fonofos and carbofuran accounted for 80% of the insecticide used.

Ohio

Table 7 gives the major compounds used in the state, and with only a few exceptions they are the same as those used in Indiana (Table 1) and Michigan (Table 4). Glyphosate and paraquat, the two herbicides most used in no till are also listed even though they are currently used very little. Table 8 gives the percentage of planted acreage treated with pesticides by crop, and the results for corn and soybeans are identical to the data for Indiana (Table 2) and Michigan (Table 5). Alfalfa in Ohio received more insecticide than in the other two states and herbicide application to small grains was intermediate between Indiana and Michigan. Table 9 gives compound

Table 4. Common and trade names of the top ten herbicides and insecticides in Michigan ranked according to annual usage (Ruppel et al, 1980).

	Common Name	Trade Name	Mode of Usage†
Herbicides			
1	Atrazine	Atrazine, Aatrex	POE, PRE, PRP-INC
2	Alachlor	Lasso	PRE, PRP-INC
3	Butylate	Sutan	PRP-INC
4	Cyanazine	Bladex	PRE, PRP-INC
5	Trifluralin	Treflan	PRP-INC
6	EPTC	Eptam, Eradicane	PRP-INC
7	Linuron	Lorox	PRE, POE
8	Chloramben	Amiben	PRE
9	2,4-D	Numerous brands	POE, PRE
10	Pyrazon	Pyramin	PRE, POE
Insecticides*			
1	Fonofos	Dyfonate	
2	Carbofuran	Furadan	
3	Carbaryl	Sevin	
4	Terbufos	Counter	
5	Phorate	Thimet	
6	Disulfoton	Di-Syston	
7	Azinphosmethyl	Guthion	

* Only seven compounds were listed.

† PRE = Preemerge; POE = Postemerge; PRP-INC = Preplant and incorporate

Table 5. Acreage of major crops treated with herbicides and insecticides in Michigan in 1978 (Ruppel et al, 1980).

	Percent of Planted Acreage Treated With:		Planted Acreage (1000 ac) Treated With:	
	Herbicides	Insecticides	Herbicides	Insecticides
Corn	97	47	2,580	1,260
Soybeans	96	2	775	18
Dry beans	96	6	550	34
Other small grains	50	9	269	48
Alfalfa	5	17	54	188
Sugarbeets	97	1	90	1
Wheat	14	1	67	7

Table 6. Herbicides and insecticides used in Michigan in 1978 by major crop (Ruppel *et al*, 1980).

	Quantities of material (100 lb) used on:							
	Corn	Soybeans	Dry beans	Wheat	Sugarbeets	Other small grains	Alfalfa	Total
Herbicides								
Atrazine	3349	--	--	--	--	--	--	3349
Alachlor	2045	720	26	--	--	--	--	2791
Butylate	1091	--	--	--	--	--	--	1091
Cyanazine	840	--	--	--	--	--	--	840
Trifluralin	--	96	683	--	--	--	--	779
EPTC	--	--	306	--	--	--	--	306
Linuron	290	--	--	--	--	--	--	290
Chloramben	159	46	--	--	--	--	--	205
2,4-D	84	--	--	26	--	75	--	185
Pyrazon	--	--	--	--	111	--	--	111
		Total						9947
Insecticides								
Fonofos	684	--	--	--	--	--	--	684
Carbofuran	516	--	--	--	--	--	33	549
Carbaryl	--	--	--	--	--	20	91	111
Terbufos	94	--	--	--	--	--	--	94
Phorate	81	--	--	--	--	--	--	81
Disulfoton	--	--	14	--	--	--	--	14
Azinphosmethyl	--	--	--	--	--	--	9	9
		Total						1542

Table 7. Common and trade names of the top ten herbicides and insecticides in Ohio in 1978 ranked according to annual usage (Carter *et al*, 1980).

	Common Name	Trade Name	Mode of Usage†
Herbicides			
1	Alachlor	Lasso	PRE, PRP -INC
2	Atrazine	Atrazine, Aatrex	POE, PRE, PRP -INC
3	Butylate	Sutan	PRP - INC
4	Cyanazine	Bladex	PRE, PRP-INC
5	Chloramben	Amiben	PRE
6	Linuron	Lorox	PRE, POE
7	Metribuzin	Lexone, Sencor	PRE, POE
8	Trifluralin	Treflan	PRP-INC
9	EPTC	Eptam, Eradicane	PRP-INC
10	2,4-D	Numerous brands	POE, PRE
	Glyphosate‡	Roundup	POE
	Paraquat ‡	Paraquat	POE
Insecticides			
1	Carbofuran	Furadan	
2	Terbufos	Counter	
3	Fonofos	Dyfonate	
4	Carbaryl	Sevin	
5	M+M*	M+M	
6	Phorate	Thimet	
7	Chlorpyrifos	Lorsban	
8	Chlordane	Chlordane	
9	Malathion	Malathion, Cythion	
10	Alfa-Tox	Alfa-Tox	

* Malathion + methoxychlor

† PRE=Preemerge; POE=Postemerge; PRP-INC: Preplant and incorporate

‡ Not presently used in large quantities, but expected to increase with shift to no till and conservation tillage.

Table 8. **Herbicide and insecticide use in Ohio by major crops in 1978 (Carter et al, 1980).**

	Percent of Planted Acreage Treated With:		Planted Acreage (1000ac) Treated With:	
	Herbicides	Insecticides	Herbicides	Insecticides
Corn	98.3	49.3	3785 (28.0)*	1898 (14.0)
Soybeans	97.4	0.7	3682 (27.2)	26 (0.2)
Wheat	4.9	1.6	59 (0.4)	19 (0.1)
Other small grains	26.9	5.3	144 (1.1)	28 (0.2)
Alfalfa	6.0	38.3	35 (0.3)	191 (1.4)

* Percent of total acres planted

application by crop. Corn and soybeans received most of the herbicide and corn almost all the insecticide, which was also true for Indiana and Michigan. The major herbicides used in the other two states, alachlor, atrazine and butylate, accounted for 72% of the total used. Chloramben was not reported in Indiana and metribuzin and 2,4-D were not reported in Michigan. Naptalam and dinoseb combination was only reported in Indiana. Table 10 gives the compounds used in the Lake Erie basin regions of Ohio. The data show that the greatest use of herbicides is in the western region where the corn and soybean acreage is greatest. Soybeans in particular are grown less in northeastern Ohio than in the other regions.

Table 11 summarizes compound use in the three states. Alachlor and atrazine alone account for 65% of the herbicides used, and with butylate they represent 77% of the total. Carbofuran, fonofos and terbufos accounted for 85% of the insecticide used. Herbicides were 89% of the total pesticides used, eight times more than insecticides.

PESTICIDE USE CHANGES WITH A CHANGE TO CONSERVATION TILLAGE

A major shift to conservation tillage in the Lake Erie basin will be concentrated in the corn and soybean growing areas of Ohio, Michigan and Indiana, and most of the emphasis will be on corn. This will require changes in the pesticide management programs for those crops and most of those changes will be in herbicide use. A shift to conservation tillage may include some of the following changes:

1. Compounds like butylate and trifluralin which require immediate and uniform incorporation will be used less.
2. Paraquat and glyphosate use for sod kill and general weed control will increase markedly. Most of the increase will be with paraquat

Table 9. Herbicides and insecticides used in Ohio in 1978 by major crop (Carter et al, 1980).

	Quantities of material (1000 lb) used on:					
	Corn	Soybeans	Wheat	Other Small Grains	Alfalfa	Total
Herbicides						
Alachlor	3282.1	3791.6	---	---	---	7073.7 (100)*
Atrazine	4451.0	---	---	---	---	4451.0 (100)
Butylate	1175.4	---	---	---	---	1175.4 (100)
Cyanazine	1140.7	1.7	---	---	---	1142.4 (100)
Chloramben	1.2	980.1	---	---	---	981.3 (100)
Linuron	4.9	778.7	---	---	---	783.6 (100)
Metribuzin	2.1	776.5	---	---	1.1	779.7 (100)
EPTC	346.9	---	---	---	17.9	364.8 (99)
2,4-D	231.3	---	21.5	49.2	1.3	303.3 (94)
Total						17655.2 (87.8%)†
Insecticides						
Carbofuran	907.2	0.9	---	---	13.7	921.8 (100)*
Terbufos	460.8	---	---	---	---	460.8 (100)
Fonofos	334.5	7.1	---	---	---	341.6 (100)
Carbaryl	20.1	18.1	0.9	3.1	34.6	76.8 (95)
M&M	---	---	---	---	43.8	43.8 (83)
Phorate	50.8	---	---	---	---	50.8 (100)
Chlorpyrifos	43.0	---	---	---	---	43.0 (100)
Chlordane	42.7	---	0.2	---	---	42.9 (100)
Malathion	5.7	---	4.2	8.7	16.4	35.0 (87)
Alfa-Tox	---	---	---	---	24.4	24.4 (98)
Total						2040.9 (92.3%)†

* Percent of the total use of that compound in Ohio.
† Percent of the total herbicide or insecticide usage in Ohio.

Table 10. Regional use of herbicides and insecticides in Ohio in 1978 on corn and soybeans combined (Carter et al, 1980).

	Northwest		Northcentral		Northeast	
	1000ac	%*	1000ac	%	1000ac	%
Herbicides						
Alachlor	658.1	17.7	690.6	18.6	204.9	5.5
Atrazine	417.6	15.2	363.7	13.2	309.9	11.3
Butylate	36.1	7.3	36.8	7.4	30.3	6.1
Cyanazine	200.4	29.5	78.9	11.6	35.9	5.3
Chloramben	545.9	67.3	80.3	9.9	1.2	0.1
Linuron	106.0	9.3	278.4	24.5	34.8	3.1
Metribuzin	367.8	25.0	234.4	16.0	9.3	0.6
Trifluralin	129.6	18.2	60.4	8.5	8.1	1.1
EPTC	---	---	2.4	3.6	0.7	1.1
Insecticides						
Carbofuran	193.7	20.5	85.1	9.0	86.9	9.2
Terbufos	52.2	12.8	19.6	4.8	41.7	10.2
Fonofos	40.6	10.0	34.3	8.4	22.5	5.5
Carbaryl	6.4	25.3	2.4	9.5	1.8	7.1
M&M	---	0.0	---	0.0	---	0.0
Phorate	15.0	30.7	3.0	6.1	5.0	10.2
Chlorpyrifos	---	0.0	1.6	3.8	3.1	7.3
Chlordane	10.3	47.2	3.0	13.8	---	0.0
Malathion	1.0	25.0	---	0.0	---	0.0
Alfa-Tox	---	0.0	---	0.0	---	0.0

* Percent of all Ohio acreage of corn and soybeans treated with that compound.

Table 11. Summary of herbicide and insecticide use in Ohio, Indiana and Michigan in 1978.

	Quantities of material (1000 lb) used on:			
	Ohio	Michigan	Indiana	Total
Herbicides				
Alachlor	7073.7	2791.0	9159.0	19,023.7
Atrazine	4451.0	3349.0	7916.2	15,716.0
Butylate	1775.4	1091.0	3327.7	6,194.0
Trifluralin	749.6	779.0	1552.7	3,081.3
Cyanazine	1142.4	840.0	635.0	2,556.4
Metribuzin	779.7	--	975.0	1,754.7
Linuron	783.6	290.0	670.0	1,743.6
EPTC	364.8	306.0	623.2	1,294.0
Chloramben	981.3	205.0	--	1,186.3
Metolachlor	--	--	776.0	776.0
	Total			53,326.0
Insecticides				
Carbofuran	921.8	549.0	1600.9	3,071.7
Fonofos	341.6	684.0	682.6	1,708.2
Terbufos	460.8	94.0	433.0	987.8
Carbaryl	76.8	111.0	171.8	359.6
Phorate	50.8	81.0	75.9	207.7
Chlorpyrifos	43.0	--	100.7	143.7
Ethoprop	--	--	91.4	91.4
Chlordane	42.9	--	35.1	78.0
M+M	43.8	--	18.5	62.3
Malathion	35.0	--	--	35.0
	Total			6,745.4

since it is considerably cheaper than glyphosate, a relatively new compound.

3. There will be a shift towards postemergent herbicides such as 2,4-D, atrazine, linuron and metribuzin, and total annual herbicide application per acre may increase somewhat.
4. Nonionic compounds are absorbed by soil organic matter and their effectiveness reduced. Application rates of these compounds to long-term continuous no till may increase as soil organic matter increases.
5. Methods for the control of above-ground insects such as armyworms or European corn borer will not change with a shift to conservation tillage, but the rate of infestation by these pests may increase with no till and also the use of insecticides to control them.
6. Soil-borne insects may increase with conservation tillage, and insecticides which require preplant soil incorporation, such as fonofos and terbufos for garden symphylan control in corn, cannot be used. Control will have to be by seed or band placement or surface application.
7. There may be a shift to broad-spectrum insecticides with some residual effect such as toxaphene. These compounds are highly toxic and the environmental hazards and restrictions on their use may prevent their widespread use in the Corn Belt.

RUNOFF LOSSES OF PESTICIDES FROM AGRICULTURAL LAND

The extent and significance of losses of pesticides from agricultural land is determined by a combination of factors: the mobility and persistence of the compound, its toxicity and accumulation by various organisms (biomagnification), and the distribution (partition) of the compound between the solid (soil or sediment) and liquid phases. Some of these factors are given in Table 12 for some of the compounds used inthe Lake Erie basin. Many of the compounds are nonionic, i.e. they have no charge, and tend to be somewhat volatile and low in water solubility. If they are insoluble and also nonionic, they will have medium to high Kd values (Table 12), which means that they tend to associate somewhat more with the sediment than with the water. If they are soluble and nonionic then they will have a low Kd (e.g. carbofuran). Compounds which have a high Kow (partition coefficient between octanol and water) also tend to be nonionic and low in water solubility. Basic compounds such as atrazine, cynazine and metribuzin are cations at low pH's and, therefore, attracted to the negative charge on soil particles. At higher pH's such as those commonly found in agricultural soils, they are nonionized and their Kd's depend on water solubility. Acidic compounds such as 2,4-D are anions at normal soil pH and, as such are repelled by soil particles. This gives them low Kd values (Table 12) and high mobilities, especially if they are water-soluble. Of those compounds in Table 12, paraquat and cyanazine have high mammalian toxicities (low LD50) and require careful handling. Fish toxicity and general environmental hazard is a function of the compounds' toxicity, persistence, mobility and biomagnification. Only chlordane and methoxychlor of those in Table 12 can be considered environmentally

Table 12. Characteristics and environmental hazard of the major herbicides and insecticides used in Ohio, Indiana and Michigan.

Name	Class	Ionization Constant (pKa)	Water Solubility (ug/ml)	Vapor Pressure (mm Hg at 20-25°C x10^-6)	Relative* Environmental Hazard	Mobility**	Longevity† (Persistence)	Toxicity‡	Biomagnification§	PEH¶	KD‖	Kow††
Herbicides												
Alachlor	Nonionic, high solubility	[illegible]	242	[illegible]	6.2	2 (3)	2	2 (1200)	1	8	20	434
Atrazine	Basic	1.7	33	0.3	8.3	2 (3)	3 (MP)	2 (3080)	1	12	3.2	213-226
Butylate	Nonionic	—	—	high	—	—	— (MP)	2 (4000)	—	—	High	—
Cyanazine	Basic	1.0	171	0.002	7.2	2	2	2 (149)	1	8	—	—
Chloramben	—	—	—	Nonvolatile	—	- (5)	—	- (3500)	—	—		11
Linuron	Nonionic, moderate solubility	[illegible]	75	15	5.7	- (2)	—	- (1500)	—	—	21.2	—
Metribuzin	Basic	1.1	1200	< 1.0	5.5	-	—	- (2200)	—	—	—	—
Trifluralin	Nonionic, low solubility	[illegible]	0.05	3.0	7.5	- (1)	(P)	- (3700)	—	—	—	1150
Pyrazon	—	—	400	—	—	—	—	- (3600)	—	—	200	—
EPTC	—	—	—	—	—	- (2)	— (MP)	2	—	—	—	—
2,4-D	Acidic	2.8	650	8.0	5.9	3 (4)	1 (NP)	1	1	3	0.78	416-426
Glyphosate	Acidic	5.6	V. soluble	—	—	Low	- (MP)	1 (4300)	—	—	—	—
Paraquat	—	—	Completely	Nonvolatile	—	1 (1)	4 (P)	1 (150)	1	4	~ 1000	1
Metolachlor	—	—	530	—		Moderate leaching		2 (2780)				
Insecticides												
Carbofuran	Nonionic, high solubility	[illegible]	700	20	8.9	2	2 (MP)	3	1	12	1.05	207
Terbufos	—	—	—	—	—	—	—					
Fonofos	—	—	—	—	—	—	— (MP)					
Carbaryl	Nonionic, moderate solubility	[illegible]	40	< 1000	6.6	2	1 (NP)	2	1	4	3.6	651
Methoxychlor	Nonionic, low solubility	[illegible]	0.1	< 1.0	11.8	1	4	4	4	64	—	2050-120000
Phorate	—	—	—	—	—	2 (1)	1 (MP)	4	1	8	8.8	893
Chlorpyrifos	—	—	—	—	—	1	1	3	3	9	—	2059-128825
Chlordane	—	—	—	—	—	1 (1)	4 (P)	4	4	64	1200	2105
Malathion	—	—	—	—	—	2	2 (MP)	3	1	6	34.1	230-776
Alfa-Tox	—	—	—	—	—	—	—	—	—	—	—	—

* Combination of mammalian toxicity (LD_{50}), fish toxicity (LC_{50}), longevity and bioaccumulation. Low = 4-7; moderate = 8-11; high = 12-16. (Weber et al, 1980).

** 1 = immobile (cation, low water solubility); 2 = intermediate (basic, water solubility between 5 and 500 ug/ml); 3 = mobile (acidic or anionic, water solubility > 500 ug/ml) (Weber, 1975). Numbers in parentheses are the mobility classes of Helling et al (1977) as reported by Chesters and Simsiman (1974). 5 is most mobile and 1 is least mobile.

† Longevity: 1 = readily degradable (< 1 month); 2 = mod. degradable (1-6 months); 3 = slowly degradable (6-18 months); 4 = persistent (> 18 months) (Weber, 1975). Letters in parentheses are the persistence scale of Rao et al (1980). NP = non persistent (half life < 20 days); MP = moderately persistent (half life 20-100 days); P = persistent (half life > 100 days).

‡ Toxicity scale of Weber (1975). Based on fish toxicity (LC_{50}). 1 = Non hazardous (LC_{50} < 100 ug/ml); 2 = slightly hazardous (LC_{50} 1-100 ug/ml); 3 = hazardous (LC_{50} 0.01 - 1 ug/ml); 4 = toxic (LC_{50} < 0.01 ug/ml). Numbers in parentheses are mammalian toxicity (LD_{50} ug/ml).

§ Classification of Weber (1975). 1 = nonaccumulative (conc. in organism is the same or lower than conc. in water); 2 = slightly accumulative (organism concentrates the compound 10 times or less); 3 = mod. accumulative (organism concentrates compound is concentrated > 1000 times by the organism).

¶ Potential Environmental Hazard (PEH). Product of Weber (1975) scales for mobility, longevity, toxicity and biomagnification. Ranges from 1 - 192.

‖ KD (adsorption partition coefficient, ml/g). Concentration of compound in sediment to that in water. Values are means of published data as presented by Rao et al (1980).

†† Kow (Octanol-water partition coefficient). Ratio of compound solubility in octanol to that in water. High Kow values indicate that the compound is nonionic. Values are for published data as presented by Rao et al (1980).

dangerous, and chlordane is no longer labelled for general agricultural use. The lower environmental hazard of the compounds in use today is primarily due to their rapid breakdown (low persistence).

Although it is always dangerous to overgeneralize, Table 12 shows that most of the compounds used in the Lake Erie basin today are nonionic, nontoxic, low to moderate persistence, somewhat mobile and with low to moderate affinity for sediment during runoff.

Measurements of Pesticides in Runoff

The amount of a pesticide compound lost in runoff will depend on the degree to which the compound has degraded or infiltrated before runoff occurs, the amount of runoff, water solubility and Kd, and soil loss. Figure 1 shows that atrazine concentrations in the surface 1-cm of soil decreased exponentially with time and reached background levels within two weeks. Atrazine losses immediately after application would be much higher than a few days afterwards, and this is shown in Figure 2 from the same watershed study (Smith et al, 1978). Both sediment-bound atrazine and that in the water phase decreased with time; the greater decline in water-soluble atrazine may be due to infiltration below the runoff zone during this period in addition to degradation of the compound itself. Figure 3 for alachlor in watershed soils and runoff (Baker and Johnson, 1979) showed that surface soil concentrations decreased exponentially with time as did alachlor in runoff water and sediment. Since most of the pesticide used in the Lake Erie basin is applied within two weeks before or after planting, pesticide losses in runoff would be primarily in the period April-June. This is a period of high runoff potential, but does not include the earlier spring thaw runoff which accounts for a significant part of the total flow and sediment load from the basin.

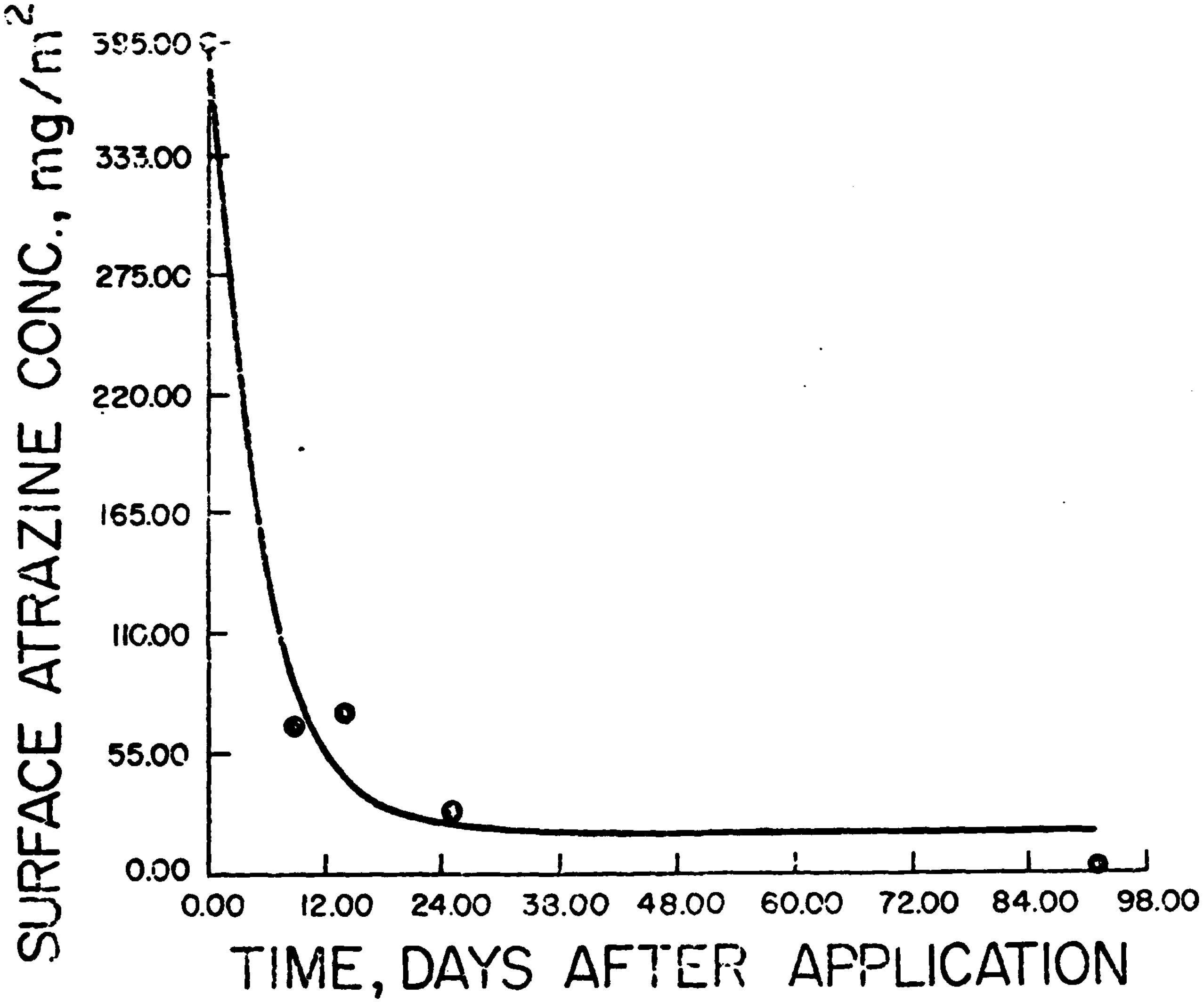

Figure 1. Persistence of atrazine in the top one centimeter of soil (Smith et al, 1978).

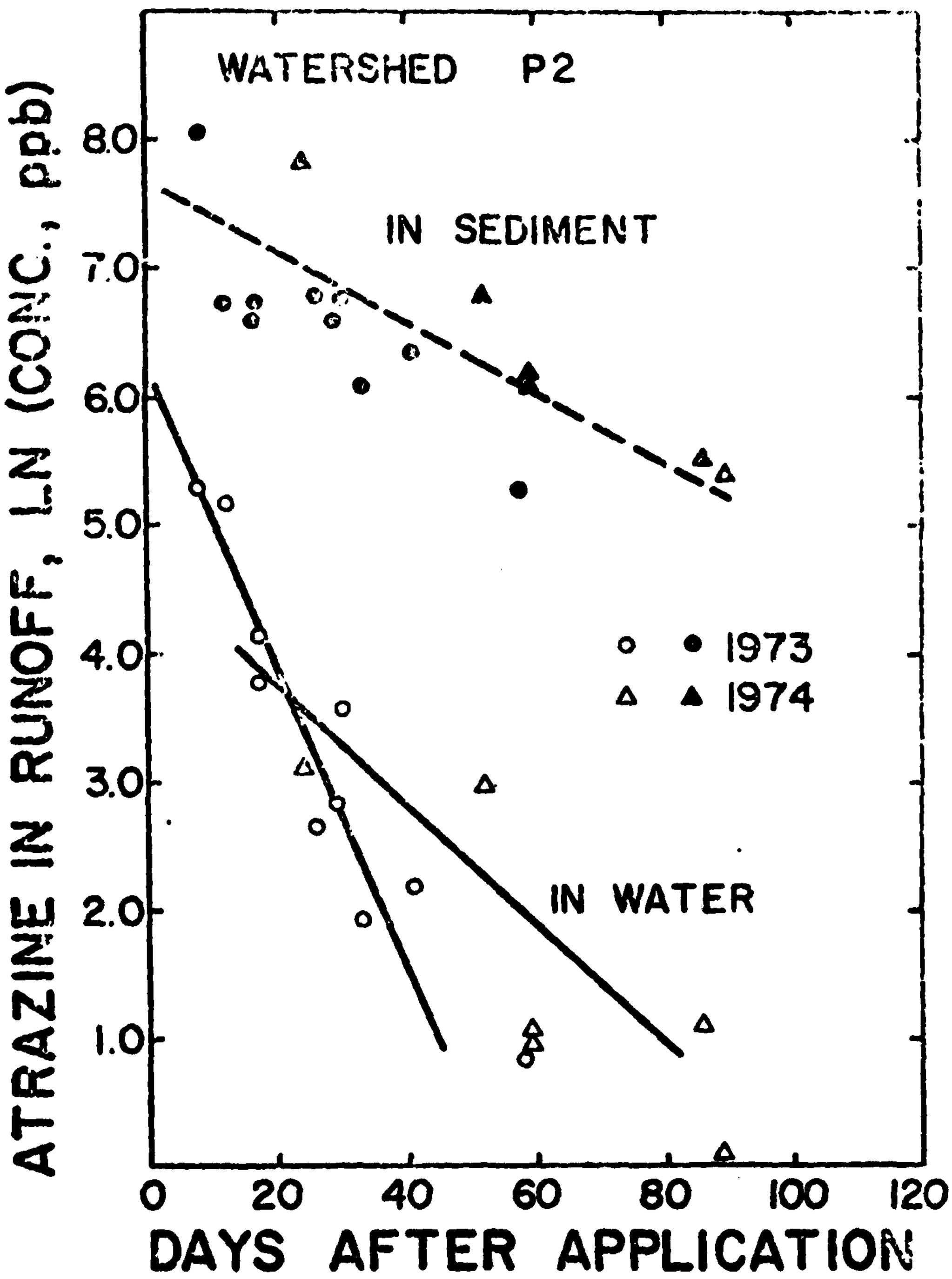

Figure 2. Concentrations of atrazine in runoff sediment and water with time after application (Smith *et al*, 1978).

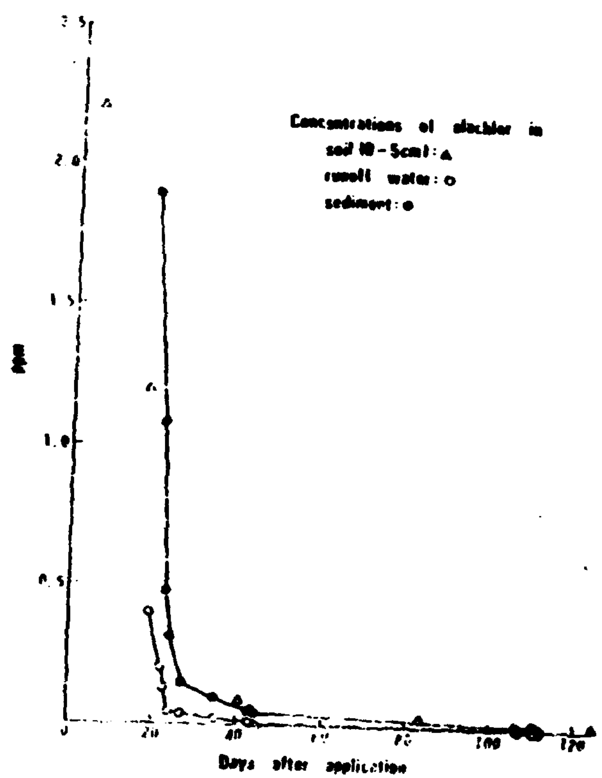

Figure 3. Concentrations of alachlor in watershed soil, runoff water and sediment with time after application (Baker and Johnson, 1979).

Weber et al (1980) have recently summarized runoff losses of pesticides in watershed and plot studies and these are given in Table 13 for those compounds used in the Lake Erie basin as well as overall means for all compounds grouped by chemical form. Atrazine runoff losses were higher than other compounds included and methoxychlor was the lowest. The overall means indicated that runoff losses were in the order:

basic >	nonionic >	acidic >	nonionic
	high		low and moderate
	solubility		solubility

Overall, about 1% of the pesticide applied was lost in runoff. Weber et al (1980) also reported on rainfall simulator studies where rain was applied immediately after the pesticide application to simulate "catastrophic" events, and about 7% of the compound was lost. These types of "catastrophic" events are probably of very low frequency and their impact on total losses of pesticides to Lake Erie is probably insignificant. However, the effect on stream biota in the immediate drainage area of the event could be significant for the more toxic compounds.

The effect on biota of toxic concentrations of pesticides in the stream occurring for very short periods of time during storm events is not well known, and unit area loads of pesticides in runoff (kg/ha), or percent of applied compound lost, may not be appropriate measures of biotic exposure. Edwards et al (1980) recently reported that a maximum of 1.85% of applied glyphosate was lost in runoff from notill watersheds in Ohio. However, in each of three years of the study, losses in the first runoff event after glyphosate application accounted for 99% of the loss from one watershed. The impact on downstream biota of the pesticide in a single annual event is not readily apparent.

Table 13. Runoff losses of herbicides and insecticides used in the Lake Erie basin (Weber et al, 1980).

Class	Compound	Crop	Tillage or Cover	Rate Applied (kg/ha) Range	Rate Applied (kg/ha) Mean	Percent of Application Lost in Runoff Range	Percent of Application Lost in Runoff Mean
Basic	Atrazine	Corn	Cultivated	0.6-9.0	2.77	0.00-15.9	2.39
Basic	Atrazine	Turf	Sod	2.24-3.92	3.08	0.04-0.84	0.44
Basic	Cyanazine	Corn	Cultivated	1.35-1.61	1.48	0.07-1.00	0.54
Basic	Metribuzin	Soybean	Cultivated	0.56	0.56	0.90-2.10	1.50
	Mean of basic compounds						2.21
Acidic	2,4-D	Corn	Cultivated	0.56-1.68	0.98	0.01-1.00	0.33
Acidic	2,4-D	Forest	Litter	9.35	9.35	<0.1	<0.1
	Mean of acidic compounds						2.01
Nonionic, high solubility	Carbofuran	Corn	Cultivated	3.11-5.41	4.23	0.47-1.90	1.08
	Mean of nonionic, high solubility compounds						1.94
Nonionic, moderate solubility	Carbaryl	Corn	Cultivated	5.03	5.03	0.15	0.15
	Mean of nonionic, moderate solubility compounds						0.46
Nonionic, low solubility	Methoxychlor	Turf	Sod	22.5	22.5	0.0047	0.0047
	Mean of nonionic, low solubility compounds						0.60
	Mean of all compounds*						1.18

*Includes many compounds not used in the Lake Erie basin.

Pesticides in Runoff with Residue Cover

The effect of residue cover on runoff losses of pesticide will depend on the solubility of the compound and its affinity for soil particles. If the effect of residue is to reduce soil loss with no change in runoff volume, then losses of compounds with a high affinity for soil such as paraquat will be reduced, but there will be little effect on soluble compounds with low Kd. Logan and Adams (1981) have shown that in some cases no till can reduce runoff or increase it relative to conventional tillage depending on soil properties. Therefore, runoff losses of water-soluble compounds could either increase or decrease depending on the soil. More significant, however, may be the timing between pesticide application and runoff-causing rainfall. Heavy rains immediately after pesticide application may produce the "catastrophic" losses reported by Weber et al (1980), about 7% of the compound applied, but more gentle rains may wash the material off of the residue and into the soil. Figure 4 shows that < 1 cm of water reduced atrazine concentrations to very low levels.

Several researchers (Weber et al, 1980; Baker and Johnson, 1979 Triplett et al, 1978) reported lower pesticide losses with increased surface cover, and all attribute the reductions to decreased runoff and soil loss. However, reductions of runoff losses of soluble compounds with low Kd values would probably be minimal or might even increase where surface cover increases or does not change runoff volume.

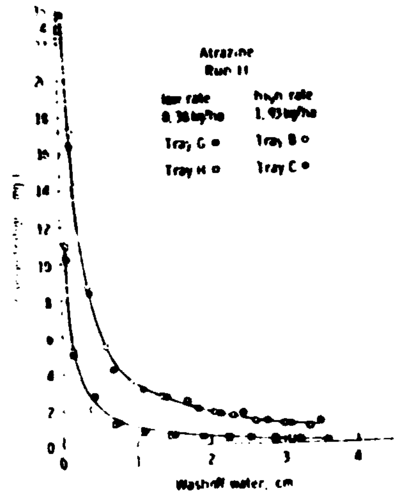

Figure 4. Concentration of atrazine in washoff water after application to corn residue (Martin et al, 1978).

CONCLUSIONS

1. Alachlor, atrazine and butylate accounted for 77% of the herbicide used in Indiana, Michigan and Ohio in 1978, and carbofuran, fonofos and terbufos represented 86% of the insecticide usage.
2. There is eight times as much herbicide applied as insecticide, and corn receives much of the herbicide and most of the insecticide.
3. The pesticide compounds presently used are relatively nontoxic to mammals and fish and low in persistence.
4. A shift to more notill and other conservation tillage systems will mean increased use of paraquat and glyphosate and reduced use of materials requiring incorporation (butylate, trifluralin). There may also be a shift to more persistent, wide spectrum insecticides such as toxaphene unless they are determined to be too environmentally unacceptable. There may be an increase in the application rate for some compounds or increased number of applications, but, in general, pesticide usage will not change markedly with a shift to conservation tillage.
5. Runoff losses of pesticides are about 1% of that applied and catastrophic losses may be as high as 7%. Losses decrease with time after application as compounds degrade or infiltrate, and most runoff losses often occur in the first event after the compound is applied.
6. Runoff losses of the pesticides used today in the Lake Erie basin not measurably change with a major shift to conservation tillage.

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